Marine Electrical Check List

A Guide to Inspecting Marine Electrical Systems

This document is available on the Internet at www.islandnet.com/robb/marine.html and it is *shareware*.

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Introduction

This document is an explanatory guide for checking marine electrical systems. There are some great, detailed publications on this subject and I recommend them for additional reading *when you have the time*…

For now, this check list will get you started with a minimum of reading. I summarised points from Canadian, American and British marine wiring regulations. However, I did not quote these publications exhaustively so don't consider *Marine Electrical Check List* a legal document.

Before working on your system, clarify any confusing points with a professional electrician.

Researching and writing this document took several months of my time -- I offer it on the Internet as *shareware*. If you read it and use it, please send US$10 using this secure online payment button:

or mail your payment to:

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Stray Current (an explanation)

Stray current is electricity that is flowing where it's not supposed to -- through water, fittings on your boat, wet wood, damp surfaces, etc. It can be a shock hazard and it can cause corrosion (technically known as *electrolytic corrosion*). Stray current corrosion is caused by a power source such as your batteries or the shore power connection. It is unlikely for serious corrosion to be caused by stray currents flowing through the water, without a metallic path to your boat. Because of the relatively high driving voltages, stray current corrosion can act far more quickly than the corrosion caused by dissimilar metals in contact (*galvanic corrosion*).

Note: The word *electrolysis* is often mistakenly used to describe various kinds of corrosion. Electrolysis actually refers to the bubbling off of gases that occurs with electrolytic corrosion.

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Common Ground Point (ship's ground)

- grounds from batteries, engine, switch-panel negative bus bar, bonding system, auxiliary power generator, underwater ground plate, ship's 120 Volt safety-ground, and LORAN signal ground all meet at one point

  This point must be a heavy bus bar or bracket with bolted connections.

  Note: When referring to 12 Volt wiring, 'ground', 'negative' and 'ground return' are all equivalent terms.

- easy to access and located as far above bilge levels as practicable
- labelled as *Common Ground Point*

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Batteries

WARNING! The hydrogen gas in and around lead-acid batteries is explosive and the acid can burn skin and eyes. Avoid sparks and wash well after handling your battery.

- acid (electrolyte) level is up to plastic liner inside holes

  Letting the acid level go below the top of the plates will kill a battery quickly. Use distilled water to top up batteries. If distilled water isn't available, tap water is OK if it's clear, not 'hard,' and not highly chlorinated. Let the cold tap run for a minute to clear metal ions out of the pipes and use a well rinsed, glass or plastic container to transfer.

- fully charged specific gravity is 1.245 to 1.300 in each cell

- In a partially discharged battery, specific gravity of each cell does not vary by more than 0.050 from the other cells

  Battery cells sometimes charge with uneven specific gravities but after discharging about 25% (from a full charge) they should even out.

  Note: If it's been awhile since charging the battery, acid may have settled to the bottom leaving a lower specific gravity electrolyte on the surface. If you overfilled the battery then the electrolyte may be diluted. Either of these situations can result in abnormally low readings and they don't necessarily indicate a weak battery cell.

- 'at rest' battery voltage is 12.1 to 12.8 Volts

  A battery is 'at rest' when it isn't being used and hasn't received a charging current for at least 12 hours. A voltage above 12.8 Volts indicates that the battery is still settling after a charge. A voltage below 12.1 Volts indicates either a weak cell or a battery charge below 50% of capacity.

  Note: Standard batteries have their life span shortened drastically by deep discharges, even to the 50% level. True deep cycle batteries (see below) function well with 50% discharges.

- engine cranks properly for 5 seconds with each battery alone -- battery voltage is above 9.5 Volts and steady while cranking

  Perform this test only after engine has been running so that protective oil has circulated. Disconnect coil '+' wire or engage diesel fuel shut-off mechanism to keep engine from starting. It's possible for batteries to fail this high current test while still being able to provide good storage capacity at lower currents.

  Note: If engine doesn't crank properly and battery voltage remains high, then there is a problem with the starting circuit or starter motor.

  Note: Starter or electric winch motors will normally 'pull' a battery's voltage down to 9 or 10 Volts while they're operating. The battery should recover most of its 'at rest' voltage within seconds.

- batteries draw not more than a few amps of charging current once they are charged

- except during conditioning (see below), water loss is at most a few ounces (50 to 100 ml) per cell, per year

  Significant water loss indicates a problem. If the water loss occurs evenly in the cells, alternator or battery charger voltages may be too high. Water loss in only one or two cells indicates weak or shorted cells.

- batteries are true deep cycle type if used for anything but starting

  Specify that you want 'golf cart' batteries because most marine/RV 'deep cycle' batteries are only marginally better than automotive batteries for deep cycling. True deep cycle batteries will provide many hundreds of charge/discharge cycles instead of only a few dozen.

  Note: Avoid discharging deep cycle batteries below 50% of their capacity. A 50% discharged battery has an 'at rest' voltage (see above) of 12.1 to 12.2 Volts.

- top surfaces clean and dry
- cables in good condition -- ends are soldered and correct size for terminal connectors

  Check cables for broken or corroded strands, especially at the ends.

- only one cable to each terminal

  In particular, avoid small wires in battery compartment. Run them to the battery switch and switch-panel negative bus bar instead.

- no connection depends on spring tension (i.e., no alligator clips)
- connections cleaned and sealed
- positive terminals have insulating cover
- negative cables go directly to Common Ground Point

  Many systems have the negative cable running directly to the engine as part of the starting circuit. This means that other negative connections need to be at the engine, or in the battery box, which can cause corrosion problems.

- positive cables go directly to nearby battery switch
- no batteries wired in parallel

  Paralleled batteries tend to fight each other when they are at rest -- this causes premature discharge and a shortened life span. It's OK to parallel batteries temporarily with the battery switch, while charging, starting and running the engine -- just avoid leaving the switch on 'BOTH' when no power is being drawn. If you require a large battery capacity, connect several 6 Volt or even 2 Volt cells in series instead of wiring 12 Volt cells in parallel.

  Note: Two batteries are in parallel if their positive terminals are connected and their negative terminals are connected.

- ventilation is provided for cooling and for venting the gases produced by batteries

  Batteries produce hydrogen, oxygen and corrosive sulphide gases. The lighter-than-air hydrogen must be able to rise naturally through a venting system, with or without a blower.

- batteries can be *conditioned* with an *equalizing current*

  After a normal full charge, conditioning consists of applying a reduced charging current (2 to 5 amps for most batteries) either for a few hours or until battery voltage rises to 15.5 - 16.5 Volts -- this takes the lead sulphate 'crust' off the battery plates and helps maintain full storage capacity. Check the acid level when finished because this process causes bubbling and fluid loss. Condition batteries every month when they're being used heavily. Conditioning requires either an override on the alternator's standard voltage regulator or a battery charger with a conditioning or 'equalising' option.

  Note: Don't condition batteries when they are in parallel or one battery may take most of the conditioning current.

  Note: Shut off all electronic equipment during conditioning because of the high battery voltage.

- inlet vent below batteries

- outlet vent as high as possible in battery compartment
- if using an electric blower for battery venting, the motor is not in the air stream
- ventilation system is for batteries only
- batteries strapped down and prevented from shifting
- battery compartment protected against acid spills
- easy to access and located as high above bilge as practicable
- if batteries are not being used, they are given a full charge at least once every 3 months

  Lead acid batteries will self-discharge over a period of months so they should be charged periodically to ensure that they don't completely discharge. This is especially important during freezing weather because a discharged battery can freeze develop cracks in the case.

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Connections

- all easily accessible and above bilge water levels

  If you must make a connection in a poorly accessible spot, solder it and seal it against moisture.

- soldered joints are first mechanically connected (crimped, bolted or twisted) -- crimped or twisted connections are soldered as well

  Connections held by solder alone will fracture with little stress. Some commercially crimped connections may be OK without soldering but most are fallible in a marine environment. Make sure solder is rosin core (60/40), not acid core.

- mechanical connections are strong (nut and bolt/stud, or machine screw into tapped metal)

  Self-tapping screws into fibreglass, wood, or thin sheet metal don't provide the consistent high pressure required for a reliable gas-tight (safe from humid air) mechanical connection.

  Note: If you must use bare wire in a mechanical connection, solder the end of the wire first. Wire strands that are 'mashed' in a connector are very susceptible to vibration breakage.

- contact surfaces of mechanical connections are clean and coated with moisture resisting sealant *before* being put together

  Note: Sealant does not need to conduct electricity. When you force two clean and sealed metal surfaces together with enough pressure, high spots in the metals press against each other and force the sealant aside. In this way, metal-to-metal contacts occur all across a connection, with 'doughnuts' of sealant surrounding each contact area. Use petroleum jelly (Vaseline), water resistant grease, or a specialty product such as Lanacote for sealant. When sealing light bulb bases, replaceable fuses and other friction connections, 'rock' the connection back and forth a few times to create good metal to metal contact while squeezing the sealant aside. Applying sealant to the exterior of existing connections will help prevent deterioration but may not last long. By sealing the interior surfaces of a connection before you put it together, you get a long lasting barrier to the moist marine environment.

- mechanical connections are locked

'Star' lock washers are best for bolted/screwed connections because they dig into the metal surfaces, providing good metal to metal contact.

- no connections made with wire nuts, wire screws or marrettes

  If you insulate a soldered connection with a wire nut, turn it up so that water can't collect in it.

- terminal connectors are ring type and correct size -- they are not 'forked' or spade connectors

  Ring type connectors hold best if a wire is accidentally pulled or a connection becomes loose. Avoid spade or other 'push on, pull off' connectors if possible. If you do use spade connectors, they must be clean and sealed, provide solid mechanical contact, be positioned so that water cannot collect in the connection, and be anchored to protect against accidental pulling on the wires. A better option is to install a terminal strip so that you can make ring terminal connections. Seal these connections as well.

- terminal strips are easy to clean type (not enclosed), with covers

- terminal strip uses minimum size #8 screws

  Stripped threads are likely on smaller sizes.

- all connections that are at a voltage different from the Common Ground Point (i.e., all positive or 'hot' connections) are insulated with shrink tubing or rubber boots

  Electrical tape does not hold up well in a marine environment. However, if tape is used for moisture sealing or to insulate an awkwardly shaped connection, secure the finishing end with a wire tie or cover as much of the tape as possible with shrink tubing to keep it from unravelling.

- wires anchored next to connections for strain relief

  In places where wire vibration or movement is unavoidable (e.g., some engine and bonding wires) make sure that only unsoldered, uncrimped wire is moving. This may require heavy duty connectors and shrink tubing on the wire next to connectors. In these situations, leave a little extra wire in a loose coil so that movement of any given section of wire is minimised and there is no chance of the wire being pulled taught.

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Wires & Cables (conductors)

- 12 Volt system is all 'two wire' type

  All devices have insulated, positive and negative wires running to them. The hull or bonding system must not be used for the ground because of potential corrosion problems.

- all wiring is stranded (no solid wire)

  Solid wire is more susceptible to vibration breakage than stranded wire. However, very finely stranded wire is likely to suffer corrosion problems so it should also be avoided.

- routed as high above bilge water levels as practicable

- conductors not kinked or bent sharply

Sharp bends will fatigue metal which eventually can cause fracturing.

- insulation is flame retardant and moisture resistant -- in bilge and engine compartment, it is oil resistant as well
- all wires have a flame retardant, moisture resistant (and oil resistant, as above) protective sheath over their insulation for the full length of the wire, except at the ends
- no frayed or cracked insulation

  The engine compartment and bilge is a likely area to have faulty insulation.

- wires are appropriate gauge for current being drawn and minimum size is 16 gauge

  Small wires break easily.

- 12 Volt system leaks less than 5 mA of current (test)

  With all circuits off and the battery switch off, connect a sensitive ammeter or LED indicator light across the battery switch contacts to indicate current leakage. Bilge pumps and their float switches are often a trouble spot so check this circuit as well if it bypasses the battery switch.

- supported at intervals of not more than 45 cm (18") unless running in bottom of conduit or trough -- supporting clips are screwed down, not nailed

  Wiring must not be able to move or flex with boat vibrations.

- if wiring is in conduit or troughs, drain holes exist to prevent collection of water
- protected from mechanical damage in exposed areas
- protected from chafing where passing through bulkheads, junction boxes, or other holes
- minimum of splices -- unavoidable splices are soldered and sealed from moisture
- wires approach terminals and devices from below (use *drip loops* if necessary)

  Water that may run along wiring must not be able to wet connections or devices.

- wire colour coding is not opposed to standards and is consistent throughout the system

  Some confusion exists with wire that is commercially available. For example, 3-conductor AC wiring should have black for the hot wire whereas most DC wiring uses black to indicate ground. To make matters worse, 2-conductor wire often comes in black AND white making it very similar to the 3-conductor AC wiring. AC standards are: hot/black, neutral/white, and safety-ground/green or bare. DC standards are: positive/red or colour coded as to purpose, and negative/black or white. When 2-conductor wire uses both black and white, white is positive and black is negative.

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Labelling & Diagrams

- every wire labelled at both ends

  Label with descriptive words for ease of trouble shooting and modification -- colour coding is often obscured by *paint and numbering requires the use of schematics. Tags can be made from white, marine-vinyl and marked with an indelible, black felt-pen. I've found 'Sharpie' extra fine points to be the best. Attach the labels with plastic wire ties. If using tape on numbers, cover them with clear shrink tubing since tape is unreliable in marine environments.*

- every electrical system is documented in diagrams or schematics and these indicate colour, relative size and labelling of wiring
- all diagrams, information sheets, operating manuals, etc. in one location on board

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Battery Switch ('master' or 'main' battery switch)

- ignition protected (enclosed) and marine rated
- easily accessible for use and maintenance
- interrupts positive cables from batteries
- located near batteries
- switches off all systems except bilge pump circuit and possibly entry alarm or electronic memories
- connections clean and sealed
- for each 'On' position, voltage drop is less than 0.5 Volts in switch while engine is cranking

  This is a test of resistance in the switch.

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Fuses, Breakers & Switches

- all circuits are fuse or breaker protected

  The only exception to this may be the starter motor circuit.

- in 12 Volt system all fuses, breakers and switches in positive side of circuits

  Breaking the negative side of a circuit can cause stray current corrosion.

- breakers are *trip free* type (cannot be overridden)
- fuses or breakers rated not more than rating of the smallest wiring they protect
- electric motor fuses or breakers rated not more than 125% of maximum motor load
- no auto-resetting breakers (e.g., thermal cut-out breakers) unless circuit is already protected by fuse or manually reset breaker
- all fuses or breakers are located in switch-panel except, perhaps, main fuse or breaker

If a fuse or breaker can't be in a switch-panel, it must be in the battery end of the circuit. In-line fuses should be avoided unless they're providing extra protection for a device on a shared circuit. They must be very accessible and the protected end of the fuse holder should connect to the positive wire coming from the battery.

- in 12 Volt system, main positive conductor to switch-panel is fuse or breaker protected as near to battery end of conductor as practicable
- fuses have clean, tight, sealed contacts
- switch-panel's wiring easily accessed for maintenance
- switch-panel ventilated
- switch-panel compartment and junction boxes not flammable and not metal
- all switches labelled
- if engine is gas powered, switches in engine and fuel tank compartments are ignition protected and approved
- switches in head, cockpit and other moist areas have rubber covers for moisture protection

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Bilge Pump System

- wiring runs above bilge water levels where possible
- float switch is protected from being jammed open by debris
- there is a high-volume, manually-operated emergency pump

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Alternator

- with engine running, batteries fully charged and a 1 or 2 Amp load on system (a light turned on), voltage to batteries is 13.9 to 14.4 Volts -- voltage remains constant as more loads are turned on, up to the rated output of the alternator

  With constant voltage regulators (most common), a high voltage setting will slowly fry the batteries unless the engine is used very little. A low voltage setting causes slow charging.

  Note: Most voltage regulators can be overridden with additional circuitry to provide fast charging while at anchor, or to condition batteries. The override circuitry can be as simple as a switched resistor or automatic as with Spa Creek's M.A.C. (Manual Alternator Control) or Cruising Equipment Co.'s QuadCycle regulator.

- **IF** it has ground terminal, a heavy wire connects it to the Common Ground Point or engine block
  ELSE: connection between alternator housing and engine block clean and sealed

  When an alternator doesn't have a separate ground terminal, the negative connection is made between the alternator housing and the engine block. This connection must then be treated the same as any other electrical *connection.*

- alternator field cut-off switch on battery switch
  OR: 'Zap stop' voltage transient suppresser on output (available from Cruising Equipment Co., Seattle)
  OR: battery isolator/charging diodes in alternator output

  Any of these devices will protect the alternator if the battery switch is accidentally shut off while the engine is running.

- power to the voltage regulator supplied through an oil pressure switch unless supplied internally from alternator

  Some regulators are powered directly from the ignition switch. This means the engine is loaded down by the alternator even before protective oil has circulated. It's better for the engine to have the alternator turn on after oil pressure has built up.

- voltage regulator is external to alternator

  Some voltage regulators are located inside the alternator housing. This makes repair or replacement a time consuming job.

- brushes and slip rings clean and in good condition

- bearings in good condition

- external connections clean and sealed

- drive belt(s) tight and in good shape

  Note: Good quality, toothed V-belts last longer and are more efficient than solid V-belts because less heat builds up in the belt.

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Starter

- **IF** starter motor has ground terminal, a heavy cable connects it to the Common Ground Point or engine block
  ELSE: connection between starter frame and engine block clean and sealed

  Since starting currents are so high, good connections are crucial. Run the engine ground cable directly to the starter's mounting bolts or to the starter's ground terminal if it has one.

- brushes and commutator clean and not too worn

- bearings/bushings in good condition

- solenoid plunger clean and lubricated

- solenoid internal contacts clean and not pitted

  High current arcing between the solenoid's main contact surfaces makes them subject to pitting and therefore poor electrical contact.

- external connections clean and sealed

- starter motor gets 9.0 Volts or more while cranking engine

  This is a test of batteries, cables, connections and solenoid.

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Anchor Winch / Windlass

- fuse or 'trip free' (cannot be overridden) breaker located in positive cable near batteries
- main current switching done through a solenoid

  Remote mounted starter solenoids, such as those used in older model Fords, are suitable. Many momentary switches are not rated for the high current drawn by winch motors or the arcing caused by such a large inductive load. Pitting in the contact surfaces can cause the switch to 'stick' and leave you with a runaway winch…

- brushes and commutator clean and not too worn
- bearings/bushings in good condition
- connections sealed and protected from anchor chain or line
- electric motor gets 9.0 Volts or more when running under load

  This is a test of batteries, cables, connections and switches/solenoids.

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Battery Isolator (charging diodes)

- alternator output voltage is raised to compensate for the voltage drop in charging diodes unless the diodes are connected *across* battery switch

  Charging diodes lower the voltage received by the batteries. If this is not accounted for, charging will occur too slowly.

  Note: If the diodes connect ACROSS battery switch, DON'T adjust the alternator output. In this case, the switch bypasses the diodes when it is 'on' -- no diode voltage drop occurs and the batteries charge normally.

- good ventilation for cooling

  Charging diodes can generate a lot of heat

  Note: Battery isolators or charging diodes only isolate batteries from each other in the alternator or charger circuit. The batteries are NOT isolated when the battery switch is on 'ALL.' To avoid the problem of paralleled batteries discharging and harming each other, the battery switch should be on 'ALL' only while starting or running the engine.

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Battery Charger

- 120 Volt side electrically isolated from 12 Volt side (test at 120 VAC if qualified)
- ammeter to indicate output
- overload protection on output
- charger shuts off completely or drops to 13.0 - 13.2 Volts (float voltage) after charging batteries

  Float voltages of 13.8 Volts or more are common and these will eventually fry your batteries. If the charger doesn't have a proper float voltage, leave it off except when you need it. It's far better to leave batteries alone, and give them a charge every few months, than to have them at a high float voltage. If you must leave a charger turned on, (e.g., with fridges or heavily used bilge pumps), make sure it has a proper float voltage.

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120 Volt AC System

WARNING! 120 Volt systems can be dangerous, especially in marine environments. Don't use your system if you have any doubts about its safety. Don't work on your system if you are unsure of what you're doing.

Following are two key points to a safe 120 Volt system:

1. The hot (black), neutral (white) and safety-ground (green or bare) wires must be intact and not mixed up (see *AC System Warning Device*, below).
2. All current must flow in the hot and neutral wires only. Current flowing anywhere else is 'stray', a fault condition and presents a shock and corrosion hazard. GFCIs (Ground Fault Circuit Interrupters) ensure or an isolation transformer that current flows only in the hot and neutral wires. GFCIs trip if they detect a loss of current from the hot or neutral wire. Isolation transformers allow current to flow only in the hot and neutral wires.

Note: No safety system protects against shock if you touch both hot and neutral wires at the same time. By touching both wires, you are no different from a light bulb or toaster since you are actually in the hot and neutral circuit. This can be fatal! Luckily, most fault conditions occur when current is able to flow outside of the hot and neutral circuit. This is the situation that GFCIs and isolation transformers protect against.

- ship to shore plug connector has a locking cover and is insulated from the hull with a rubber gasket
- ganged, double-pole main breaker is the first part of ship's system and it is easily accessible

  The main breaker must disconnect both hot (black) and neutral (white) wires simultaneously.

- main breaker rating is appropriate for ship to shore plug connector and wiring used
- all power indicating devices are wired to hot (black) and neutral (white) wires only unless switched by a 'momentary on' switch

  For example, reverse polarity (hot and neutral reversed) detectors are wired between neutral and safety ground or ship's ground. If the detector is permanently wired into the circuit, it can cause stray current corrosion by allowing current to flow in the safety-grounds or through the bonding system.

  Note: A momentary switch is not required if the device uses circuitry to keep it from drawing more than 1 mA in safety-grounds, ship's ground, or bonding system.

- AC system warning device is testable and indicates reverse polarity, open safety-ground, hot on ground, etc. (all are dangerous conditions)

  Note: Unless your AC safety indicating system is quite sophisticated, it is a good idea to have a plug-in AC outlet tester. They cost $10 to $15 and test most dangerous conditions with their 3 lights. Do not leave this tester plugged in because it causes current to flow in the safety-ground, which is a cause of stray current corrosion.

- no connection from either hot (black) or neutral (white) wires to any part of 12 Volt system, including bonding system (test at 120 VAC if qualified)

  A connection between 120 Volt AC hot or neutral wires and the 12 Volt system would be potentially dangerous and could cause stray current corrosion. This problem can occur with AC appliances, such as battery chargers or hot water heaters, and with poor insulation, wet connections, or broken wires.

- wiring is stranded 3-conductor and is 14 gauge minimum

- ends of bare wires are soldered before screw connecting

  Bare stranded wire will break easily if it is 'mashed' under a screw head.

- all connections (especially 'hot' ones) in switch-panel or other accessible areas are insulated

  Many commercially available panels contain both AC and DC systems, with all terminals exposed. The 120 Volt terminals must be insulated for safety.

- all connections are accessible only with the use of tools

  We wouldn't want tiny exploring hands endangering themselves would we?

- all switches, fuses and breakers disrupt the hot (black) wire

  Breakers may be the ganged, double-pole type, which disrupts both hot and neutral (white) wires simultaneously. The neutral wire must not be broken while the hot wire is intact.

- no fuses, breakers, or switches in safety-ground (green or bare)

- outlets in head and galley are protected by a GFCI (Ground Fault Circuit Interrupter)

  Most regulatory bodies require GFCI protection in heads and galleys since they tend to be especially wet spaces. However, since boats can be wet all over I highly recommended that GFCIs or an isolation transformer be installed to protect the entire 120 Volt system.

- all 120 Volt outlets are 3 prong, grounding type and are incompatible with 12 Volt DC outlets

- outlet faces clean and terminals coated with a moisture resistant sealant such as petroleum jelly

  120 Volt AC current leakage is likely with dirty or moist outlets. This leakage can cause GFCI devices to trip and, in extreme cases, can cause stray current corrosion or be a shock hazard.

- if there's an on board 120 Volt AC power source (generator or inverter) wired into the system, there is a DPDT (double-pole, double-throw) switch in the hot (black) and neutral (white) wires that switches the system between shore power and ship's AC power source

  Shore power and the ship's AC power source must not connect to each other or sparks can fly!

- all wiring enters its destination from below (or in a way that won't allow water drips to enter)

- AC system is one of the following three types:

1. Fully GFCI protected:

    - all circuits protected by GFCI (Ground Fault Circuit Interrupter) devices

      GFCIs are available as both circuit breakers and outlets. GFCI outlets must be in a circuit already protected by a circuit breaker (usually 20 Amp maximum)they do not function as an overload protector. GFCI outlets can be wired to protect the rest of the circuit, continuing from that outlet. GFCI devices must have a test feature and they should be tested monthly to ensure safety and corrosion protection.

      Note: The entire AC system could be protected by a single GFCI main breaker. However, this is not advisable if you have many AC circuits because the combined leakage of all AC devices could trip the GFCI unnecessarily. For large systems each circuit should have its own GFCI device.

    - shore safety-ground (green or bare) continues as far as first GFCI device, stops there and does not connect to anything at that point

    - ship's safety-ground (green or bare) starts at the first GFCI device, connects to GFCI and its box and continues from there

    - ship's safety-ground is connected to Common Ground Point

    - no connection from shore safety-ground to Common Ground Point (test at 120 VAC if qualified)

      The connection from shore safety-ground to ship's ground can allow stray current corrosion. This connection is safely avoided only with complete GFCI protection or an isolation transformer system.

2. Isolation transformer protected:

    - all AC current supplied through an isolation transformer located between main breaker and switch-panel

      The transformer should be marine rated and large enough to supply all circuits used on board.

    - if neither secondary wires (ship side of transformer) are grounded to Common Ground Point, all circuit breakers are ganged, double-pole type

    - shore safety-ground (green or bare) connected to isolation transformer case only

    - ship's safety-ground (green or bare) connected to Common Ground Point

    - no connection from shore safety-ground to Common Ground Point (test at 120 VAC if qualified)

      The connection from shore safety-ground to ship's ground can allow stray current corrosion. This connection is safely avoided only with complete GFCI protection or an isolation transformer system.

      Note: GFCIs are not required with a correctly operating isolation transformer but may be added as protection against a malfunctioning transformer.

3. Incomplete GFCIs, no isolation:

    - missing or incomplete GFCI (Ground Fault Interrupter) protection and no isolation transformer

    - AC safety-grounds (green or bare) from shore and ship are connected together and to Common Ground Point

In this system, the connection between ship and shore safety grounds, and ship's ground is critical for protection against shock hazard and stray current corrosion. This connection does not protect against someone touching the hot (black) wire directly while in contact with bilge, sea, or bonding system. A GFCI or isolation transformer system would protect in this case.

Note: Connecting the ship's safety-ground to ship's ground only, or to shore safety-ground only, can create a shock and corrosion hazard in this system.

Note: Without complete GFCI or isolation transformer protection, the safety-ground system must be solid on boat and shore to get the protection it can provide. While this 120 Volt AC system is common, it provides limited safety protection and allows several kinds of stray current corrosion to occur since your boat's underwater metal parts are electrically connected to other boats and to the shore system ground. DC stray current can be blocked with a 'galvanic isolator' (diode or capacitor type) connected in series with the safety-ground wire. However, high voltage AC stray current cannot be blocked safely. For these reasons, the full GFCI or isolation transformer systems (#1 and #2 above), which safely eliminate the shore safety-ground to ship's ground connection, are highly recommended.

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Meters

- DC voltmeter can be read to nearest 0.1 Volt

  A voltmeter allows monitoring of alternator and charger operation. A sensitive voltmeter will also indicate storage capacity remaining in batteries.

- DC ammeter showing alternator output

  An ammeter is usually part of engine instrumentation. It allows monitoring of alternator operation.

- DC ammeter indicating power drawn from batteries

  An ammeter for the switch-panel can indicate faults in individual circuits. The meter's resolution should be better than 1 Amp (.01 Amp or 1 mA resolution is best). An indicator light for small current leaks is desirable and simple to install.

  Note: The connections on DC ammeters (or their shunts) carry full current so they must be clean, sealed and locked.

- AC voltmeter and ammeter in system if shore power used extensively or if there's an on board AC generator (alternator)

  AC meters show the status of shore power or generating system and can indicate faults in the ship's AC system.

Note: A meter can be installed to monitor the functioning of your zinc, anti-corrosion system.

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Bonding and Lightning Protection

Four reasons for a bonding system are:

1. Electrically connect metal fittings for corrosion protection systems.
2. Protect metal fittings from stray currents originating on board.
3. Reduce electronic interference (noise) for LORAN and radios.
4. Provide a safe path for lightning strikes and the high voltages induced in metal objects by a lightning strike.

- system uses heavy conductors -- minimum size is 8 gauge wire or 1 mm x 10 mm (1/32" x 1/2") copper or bronze bar

  Some sources recommend a heavier conductor (up to 2/0 gauge) for the main lightning path which is down the mast, along the main bonding conductor, and out to the shaft and prop and/or underwater grounding plate.

- all connections above normal bilge water levels

- all connections accessible, clean, bolted and soldered or sealed

  Soldered connections must first be well connected mechanically since solder is weak. Also, solder can melt with the high current of a lightening strike.

- conductors are run with no sharp kinks or bends

  Sharp bends will fatigue metal and can eventually cause fracturing.

- conductors run separate from other wiring as much as practicable

  The high current of a lightning strike can cause equipment damaging voltages to be induced in nearby wiring.

- insulation (optional) is green or yellow

  Note: This system is separate from the 120 Volt safety-grounds which may also be green.

- does not normally carry current (except for corrosion protection current)

  Do not use the bonding system in place of negative power wires (i.e., as a 'ground return') or stray current corrosion problems can result.

- the 'main bonding conductor' runs near the centre line of the ship and connects to the Common Ground Point -- all other bonding conductors connect to the main bonding conductor or directly to the Common Ground Point

  Running bonding conductors from one fitting to another increases the risk of shock and corrosion damage if stray currents run through the bonding system. Each bonded fitting should have only one connection point and one wire running to it.

- bonding system connects with DC power system at Common Ground Point only (test)

- The following connections exist to reduce the danger from stray currents originating on board:

  Note: These connections also provide the basis for hull-mounted-zinc or impressed-current corrosion protection systems and are part of the lightning protection system.

  - rudder shaft (if not mild steel) to main bonding conductor

  - trim tabs to main bonding conductor

  - propeller and shaft to main bonding conductor via wiper on shaft

    The prop shaft wiper provides a path for corrosion protection current. It also allows lightning strikes to *ground through the propeller (at least one square foot of underwater metal is required). Make sure that wiper is on the propeller side of any non-conducting, flexible shaft couplers or install a jumper wire over the shaft coupler.*

Note: Electrical contact through lubricated gears and bearings is unreliable. Therefore, the engine block connection must not be counted on to connect the propeller and shaft to the bonding system.

- shaft support strut/bracket (if not mild steel) to main bonding conductor

- metal through-hull fittings to main bonding conductor

  Thru-hull fittings that are electrically isolated, in little danger of stray current corrosion and remote from protective zincs, need not be bonded (fittings that are far away from your zincs are not protected anyway). Keeping these fittings unbonded is desirable since a large system is more likely to pick up stray currents flowing through the water.

- if equipped with underwater ground plate, it is connected to Common Ground Point

- engine block to Common Ground Point

  The engine block is often connected to the Common Ground Point as part of the starting circuit.

- other metal components, that are exposed to water and require protection from corrosion or stray currents, are connected to the main bonding conductor.

  Note: Underwater metals that are widely separated in the Galvanic series (e.g., mild steel and stainless steel) must not be electrically connected. For example, a mild steel rudder should have its own attached zinc and must not be connected to a bonding system containing bronzes or stainless steel. Otherwise, the brasses and stainless steels will be over-protected, causing wasted battery power or a shortened zinc life span and possible alkali rot in wood hulls. Also, if the corrosion protection system were to fail, the mild steel would be attacked by the more noble brasses and stainless steels. With zinc or impressed-current protection, bronze, stainless steel, monel, lead and some other alloys are compatible.

- The following connections exist for lightning protection:

  - each piece of metal standing rigging (stays and shrouds) to main bonding conductor

  - if mast is metal, mast base to main bonding conductor

  - if mast is not metal, a copper spike extends 15 cm (6") above top of mast and a conductor runs from the spike down mast to main bonding conductor

    If lightning does not have a metallic path to the sea, it can travel through wood or you causing serious damage.

  - if equipped with masthead antenna, it is a metal whip on a base loading coil and it is well connected to mast or mast conductor

    Various kinds of lightning arresters are available to provide protection for antenna cables and radios.

  - all metal parts of fuel system (tanks, lines, electric pumps, valves and fill fittings) to main bonding conductor

  - metal water and holding tanks and their fill hardware on deck to main bonding conductor

  - large or long metallic items (steering and engine control cables, sail tracks, stanchions and life lines, pulpit, cockpit railing, stove, chimneys, sinks, metal cabinets, etc.) to main bonding conductor

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Corrosion Protection

- if hull is wood, all fasteners are same type of metal

  In wet wood, different metals that are near to each other can cause galvanic corrosion to the less noble metal (zinc is one of the least noble metals). For example, galvanised fasteners would have a shortened life if bronze fasteners were nearby.

- galvanized fasteners used underwater are hot-dipped type

  Zinc plated fasteners will rust quite quickly because the protective plating is not very thick compared to a hot-dipped zinc coating.

- fasteners or fittings that are exposed to water are not made of brass, naval bronze, or manganese bronze

  These metals have a high zinc content and will corrode severely due to 'dezincification.' Most true bronzes (silicon, aluminum, or phosphor bronze) are OK under water, provided they aren't in contact with incompatible metals.

  Note: Do not use household-plumbing type gate valves in salt water systems because they are usually made of brass.

  Note: Propellers and shafts are sometimes made of brass or manganese bronze. Dezincification of these fittings can be slowed down with zinc or impressed-current protection systems.

- fasteners are same metal as fittings, or slightly more noble than fitting

  Note: Through-hulls are a particular problem area for underwater corrosion. Through-hulls and their fasteners should both be made of a true bronze.

- no copper in areas of fast moving water (e.g., exhaust elbows)

  Copper corrodes very little in still water but suffers from impingement attack (a type of corrosion) in fast moving water.

- no copper alloys (brass, bronze, etc.) within 60 cm (2') of aluminum outdrive

  Underwater aluminum can corrode severely in the vicinity of copper so existing copper alloy parts should be painted with epoxy paint to help minimise their impact.

- no electrical path from underwater aluminum to any other underwater metals (test)

  Underwater aluminum will galvanically corrode when electrically connected to most other underwater metals. Magnesium and zinc are exceptions that can be used to protect aluminum.

- aluminum masts, outdrives or other fittings exposed to the weather use stainless steel fasteners and are in contact with no metals other than aluminum, stainless steel, galvanised steel, or monel

  Copper and copper alloys such as brass and bronze must not be joined to aluminum that is exposed to the weather because of the vigorous galvanic corrosion that they can cause. Stainless steel is much more noble (further from *zinc) than aluminum but it develops a protective oxide coating so corrosion of the aluminum is minimal. Also, the corrosive effects of a small stainless fastener are spread out over a relatively large area of the aluminum fitting and so it will do little concentrated damage.*

- hot-dipped zinc or galvanised metals (chains, anchors, etc.) in contact with galvanised, hot-dipped, or mild steel metals only

  Severe corrosion can result from mixing these metals incorrectly. Do not use galvanised chain on a stainless steel anchor, stainless shackles on galvanised chain, or stainless wire on a galvanised shackle, etc.

- stainless steel used with caution underwater

  Stainless is great underwater except when oxygen is not available to its surface, as happens under marine growth, in wet wood, inside stuffing blocks and rubber bearings, and underneath fittings. When stainless is in these common situations, deep pitting (crevice corrosion) of the metal can occur and structural failure can result. If stainless components are used underwater, they must be well bedded in waterproof 'goop' to exclude moisture from underneath the fitting and they should be inspected annually to check for pitting. Stainless fasteners in damp wood are particularly prone to crevice corrosion and should definitely be avoided. If stainless fasteners or bolts are used underwater, lots of goop must be placed on their threads, in the pre-drilled hole and under and around the head of the fastener to seal out moisture. These fasteners or bolts must be withdrawn periodically to inspect for crevice corrosion.

  Note: Stainless steel that is connected to a zinc or impressed-current protection system will not necessarily be protected. Crevice corrosion occurs where oxygen cannot get to the metal's surface. If oxygen can't get to the surface then it's very likely that protective current won't be able to either.

  Note: Use only 'austenitic' stainless steels in marine applications. These steels can be differentiated from other steels with a magnet, which will attract them very weakly or not at all. The stainless should preferably be type 316 or better. Type 304, or 18/8, stainless is the most common but is not as corrosion resistant as 316.

- if propeller, prop shaft, or rudder shaft are stainless steel, waterproof grease or thread sealant is used to keep salt water out of threads, shaft taper and key way

  Note: Make sure grease is not graphite based.

- underwater stainless fittings are fastened with monel fasteners

- no gaskets containing asbestos or graphite and no underwater use of graphite based grease or graphite impregnated packing

  Asbestos and graphite are very noble in the galvanic series (opposite of zinc) and will, therefore, corrode most metals they are in contact with.

- no copper, mercury, or lead based anti-fouling paint on aluminum or mild steel

  In general, no metal based anti-fouling paint should be used on metal unless you know that they are compatible or an appropriate type of sealer coat is first applied to the bare metal.

- keel bolts in good condition and compatible with keel material

- centreboard pivot and lifting gear in good condition and made of compatible materials

- fittings that are in the bonding system are painted and isolated from wood as much as practicable

  Painting a fitting will reduce the amount of protective current it requires. Isolating it from the wood with paint or gaskets will protect the wood from hydroxides created by the protective current. These precautions minimise the *damage by alkali rot to wood around protected fittings.*

- if engine or its cooling system uses internal zinc protection, zincs are not corroded away

Zinc corrosion protection system:

A protective current flows through metals that are electrically connected to the zinc. The current is forced by the galvanic voltage difference between zinc and the underwater metal parts of the boat. Metals that are too far away from the zinc will receive little protective current.

- zincs are bright, unpainted and not corroded away

  Note: There may be zincs in the engine block, in heat exchangers, on the rudder, or on outdrives.

- zinc connection locked with star washer and moisture sealed

  Zincs that are cast around a mounting bar are best. If you have stud mounted zincs, use a waterproof goop to seal in and around the mounting hole. This will help prevent corrosion that can lead to loosening of the zinc by undermining the stud connection.

- shaft zincs not too near propeller

  A zinc on the shaft can cause turbulence which will decrease the efficiency of the propeller. Shaft zincs also tend to protect only the forward part of the propeller. It's better to have hull-mounted-zincs connected to the shaft via a shaft wiper (see *Bonding System**).*

- appropriate protection current is flowing (10 to 25 mA, or more, per square foot of bare metal to be protected, depending on many factors)

  Note: Too much protective current can seriously damage wood or, in extreme cases, aluminum around protected fittings. Too little current will not provide adequate protection of fittings. With a wood hull, it's cheaper to err on the side of too little protective current since most underwater fittings are reasonably corrosion resistant anyway.

- there is a meter for monitoring protection current

  A protection current meter is easy to install with a hull-mounted-zinc system. It will show how much protection is being given and when zincs need replacing. It will also indicate problems in the system, including stray currents. The meter should be 1 Amp (1000 mA) full scale and have a remote shunt. The shunt should have a pair of 40 Amp Schottky diodes wired in parallel with it, one in each direction, to protect the meter from lightning or electrical fault current surges. The remote shunt is important for allowing lightning strikes to flow directly to the sea, without first being routed up to your meter location.

  Note: Stray currents picked up by a bonding system will corrode any attached zincs before damaging other metals.

Current limiting systems:

These systems are essentially the same as a hull-mounted-zinc system except that current limiting circuitry is placed in the wire running to the sacrificial zinc, allowing an extra large zinc to be used. Current is held at an appropriate level and the zinc may last for several years or more. These systems may have reference anodes mounted on the hull as well as the sacrificial zincs.

- follow manufacturer's instructions for maintenance and make sure it's working…

Impressed-current systems:

Impressed-current systems 'force' a protective current to flow, using battery voltage instead of the natural voltage present between zinc and the bonding system. An underwater anode is still required but it is made of some non-corroding metal instead of zinc. Reference anodes may also be required with this system.

- follow manufacturer's instructions for maintenance and make sure it's working…

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Compass (traditional, fluxgate and autopilot compasses)

- not affected by operation of any of ship's equipment -- check on two perpendicular headings (e.g., N and W)

  Any DC current flow and most electronic devices can affect the compass if they're nearby. Check everything.

Note: AC current does not affect compasses so the next three points do not apply to 120 Volt wiring.

- no wires carrying heavy current nearby
- no single wires near compass

  The switch-panel's main ground wire and the alternator output wire are examples of potential problems because they carry a lot of current and they often run alone. When both positive and negative wires of a circuit run together, their opposite magnetic fields tend to cancel each other out.

- if wiring is nearby, it has both conductors tightly twisted together
- no speakers, swinging needle meters, transformers, ignition coils, or other magnetic devices nearby

  Speakers often contain powerful permanent magnets. They should be at least 1.5 m (5') away from any compass.

- no metal objects nearby unless they're non-magnetic

  Steel and iron usually cause most of the problems. Stainless steel and aluminum should be OK. All nearby metals should have their effect on the compass checked.

- autopilot and steering compasses separated by 1 m (3') or more (check their effect on each other)

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Electrical Interference (noise)

- GPS, LORAN, autopilot, VHF, RADAR, depth sounder, etc. continue to operate properly when other electrical systems are turned on -- **Do not perform this test with engine starting circuit or winch motor!**

  No electronic device should be 'on' while the engine is being started or the winch is operating unless they are in an isolated circuit. The voltage transients or 'spikes' generated by starter and winch motors can cause damage to sensitive electronics. In this test, watch for noise generated by gas engine ignition systems, alternator, DC to AC inverters, depth sounder, RADAR, strobe light, fluorescent lighting, electric motors, electric fuel pumps, VHF and SSB radios. Note that electronic noise can be transmitted through wires or air. For example, a LORAN may have poor reception due to noise in its power cable or noise picked up by its antenna.

- autopilot, RADAR, inverter and SSB radio have their own circuits, with the wires running separately from wires for sensitive electronics

- able to isolate autopilot circuit

  Some electric autopilot motors can cause noise problems for electronics (e.g., LORAN). If this happens, isolation is desirable. This can be achieved by directly wiring the autopilot circuit to one battery (at battery switch) and running the system on the other battery. Alternatively, the LORAN can have an isolated power supply by having its own small battery, which is wired to the system with appropriate filters for charging.

- LORAN has at least 8 gauge conductor for 'signal ground' connection to Common Ground Point

- power wires for sensitive devices run separately from other wiring, especially alternator output, engine instrument and electric motor wires

  Wires that run parallel and close to each other can cause problems. However, wires may cross without affecting each other. Shielding may be required if close parallel wiring can't be avoided.

  If noise problems continue after following the above suggestions, filtering of offending and/or sensitive circuits may be necessary

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Miscellaneous

- depth sounder transducer is free of marine growth and has thin or no paint layer on bottom surface

- if propane or gasoline are used on board, appropriate sensing devices are installed to warn of leaks

- autopilot, VHF, RADAR, SSB and other critical, high-power devices have an input voltage that differs from battery voltage by less than 0.5 Volts while operating

  The voltage drop in a circuit is an indication of the condition of connectors, switches and wiring.

- solar panels have diodes in their circuits

  Without diodes, solar panels can take power from the batteries at night.

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Pre-Cruise Mini Check List

Maintenance check points are covered only briefly here. For explanations and construction check points, see the main sections of the check list

Batteries

- top surfaces clean and dry
- acid (electrolyte) level up to plastic liner inside holes
- fully charged specific gravity is 1.245 to 1.300 in each cell
- In a partially discharged battery, specific gravity of each cell does not vary by more than 0.050 from the other cells
- 'at rest' battery voltage is 12.1 to 12.8 Volts
- engine cranks properly for 5 seconds with each battery alone -- battery voltage is above 9.5 Volts and steady, while cranking
- cables are in good condition

- connections clean and sealed from moisture

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Wiring & Connections

- contact surfaces of mechanical connections are cleaned and coated with moisture resisting sealant *before* being put together
- no frayed or cracked insulation (check bilge and engine compartment)
- 12 Volt system leaks less than 5 mA of current (test)
- battery switch connections clean and sealed
- for each 'on' position, voltage drop is less than 0.5 Volts in battery switch, while engine is cranking
- fuses have clean, tight, sealed contacts
- every electrical system is documented in diagrams or schematics and these are in one location on board

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Alternator, Starter & Winch Motor

- with engine running, batteries fully charged, and a 1 or 2 Amp load on system (a light turned on), voltage to batteries is 13.9 to 14.4 Volts -- voltage remains constant as more loads are turned on, up to the rated output of the alternator
- brushes and slip rings or commutators are clean and in good condition
- bearings or bushings in good condition
- external connections clean, sealed from moisture, and positive terminals are covered
- alternator drive belt(s) tight and in good shape
- starter solenoid plunger clean and lubricated
- solenoid internal contacts clean and not pitted
- starter and winch motors get 9.0 Volts or more while operating

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Miscellaneous

- 120 Volt AC outlet faces clean and terminals coated with a moisture resistant sealant such as petroleum jelly
- underwater stainless steel fittings and fasteners not pitted
- if engine or its cooling system uses internal zinc protection, zincs are not corroded away
- corrosion protection zincs bright, unpainted and not corroded away
- in corrosion protection system, appropriate protection current is flowing (10 to 25 mA, or more, per square foot of bare metal to be protected, depending on many factors)
- compasses not affected by operation of any of ship's equipment -- check on two perpendicular headings (e.g., N and W)
- LORAN, autopilot, VHF, RADAR, etc. continue to operate properly when other electrical systems are turned on -- **Do not perform this test with engine starting circuit or winch motor!**
- depth sounder transducer is free of marine growth and has thin or no paint layer on bottom surface
- if propane or gasoline are used on board, appropriate sensing devices are installed to warn of leaks
- autopilot, VHF, RADAR, SSB and other critical, high-power devices have input voltage different from battery voltage by less than 0.5 Volts while operating

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Electrical System Spares

- fuses (check electronic devices for internal fuses)
- bulbs
- VHF antenna that will connect directly to radio

- alternator belt
- alternator brushes (most alternators have brushes)
- voltage regulator for alternator and/or a method of 'hot wiring' alternator field coils for emergency charging
- 4 litres (1 gallon) of distilled water
- engine starter solenoid
- winch motor solenoid
- if gas engine, complete set of ignition system parts
- plug-in AC outlet tester (has 3 indicator lights, costs $10 to $15)

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